H $\longrightarrow b\bar{b}$ in VBF with an extra central photon

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Outline

- Relevance of a measurement of the $Hb\bar{b}$ Yukawa coupling (low Higgs mass range)
- $t\bar{t}H(\to b\bar{b})$ very challenging (see the discussion of last week)
- $H(\to b\bar{b})$ in VBF was studied few years ago at parton level. But recent “pessimistic” indications from complete simulations
- Proposal: $H(\to b\bar{b})$ plus an additional γ in VBF mode
    - Features of radiation patterns in signal and background allow to obtain good $S/\sqrt{B}$ (at parton level), balancing the drop of signal events w.r.t. the signal without γ
    - The same patterns remove the “contamination” from ZZH vertex
    - Parton level study of signal and background (irreducible and reducible) with “optimized cuts”
    - The significance could be improved considering showering effects and jet veto strategies
- Summary

$H \longrightarrow b\bar{b}$ in VBF

The VBF production mode has been studied at parton level with ALPGEN in

M.L. Mangano, M. Moretti, F. P., R. Pittau and A.D. Polosa, Phys. Lett. B556 (2003) 50

- Typical signature: central $b\bar{b}$ pair $+$ pair of jets in the fwd and bckwd rapidity region
- Main backgrounds:
  - QCD $b\bar{b}jj$ production
  - QCD four jets production (with two light jets mistagged as b jets)
  - QCD $Z(\rightarrow b\bar{b})jj$
  - QCD $W/Z(\rightarrow jj)b\bar{b}$
  - QCD $t\bar{t} \rightarrow b\bar{b}+$ jets
  - QCD multiple overlapping events (especially at high luminosity)

Event selection

$$
\begin{aligned}
p_{\mathrm{T}}^{b} > 30\ \mathrm{GeV},\ |\eta_b| &< 2.5,\ \Delta R_{bb} > 0.7 \\
|m_{bb} - m_H| &< \delta_m \cdot m_H \\
\epsilon_b &= 0.5
\end{aligned}
$$

$$
\begin{aligned}
p_{\mathrm{T}}^{j} > 60\ \mathrm{GeV},\ |\eta_{j_1} - \eta_{j_2}| &> 4.2,\ \Delta R_{jj},\ \Delta R_{jb} > 0.7 \\
m_{jj} &> 1000\ \mathrm{GeV} \\
0.01 < \epsilon_{\mathrm{mis}} &< 0.05
\end{aligned}
$$

- selection a) $2.5 < |\eta_j| < 5$, $\eta_{j_1}\eta_{j_2} < 0$, $\Delta R_{bb} < 2$
- selection b) $|\eta_j| < 5$
- The cut $|\eta_{j_1} - \eta_{j_2}| > 4.2$ allows to suppress the “background” due to H + 2 jets QCD production

V. Del Duca et al., Phys. Rev. Lett. 87, 122001 (2001)

Main results of that study

- Good $S/\sqrt{B}$ significances (at parton level) with 600 fb^{-1} of integrated luminosity (at the level of about 5σ for $m_H < 130$ GeV)
- But...
  - S/B of the order of 0.5%
  - trigger problems
    - no leptons to trigger on
    - large QCD $4-$jet cross sections also with large p_{T} thresholds (60 GeV) $\Rightarrow$ potential problems for registering all relevant events on tape without loosing signal
- Recent results with full detector simulation seem to give more pessimistic results

some numbers

m_H	115 GeV	120 GeV	140 GeV
Signal	3.0×10^3	2.8×10^3	1.1×10^3
$b\bar{b}jj$	8.6×10^5	8.0×10^5	5.7×10^5
$j_b j_b jj$	6.4×10^3	6.1×10^3	4.1×10^3
$(Z^*/\gamma^* \to b\bar{b})jj$	5.5×10^2	3.8×10^2	1.0×10^2
$(Z \to b\bar{b})_{\rm res}jj$	1.3×10^3	6.8×10^2	1.1×10^1
$j_b j \oplus j_b j$	7.5×10^3	7.9×10^3	9.0×10^3

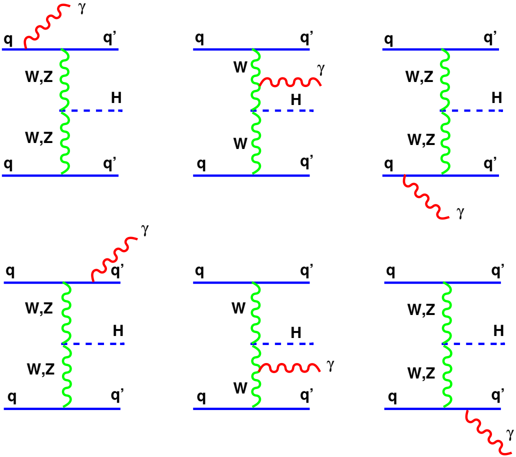
Signal and background events for configuration (a), with $p_{\rm T}^j > 60$ GeV, for three possible values of the Higgs mass. $Q^2 = \langle {p_{\rm T}}^2 \rangle$. The $jjjj$ entry includes the squared $b-$mistagging efficiency ($\epsilon_{fake} = 0.01$). The first raw relative to the Z^*/γ^* contribution refers to the effect of the physical mass tail, while the second raw refers to the finite experimental Z mass resolution, $(\delta m_Z/m_Z = 0.12)$. The integrated luminosity is 600 fb^{-1}. The PDF set used is CTEQ4L

Adding a γ would seem hopeless

- Naively signal and background expected to drop by a factor of the order of α $(S/\sqrt{B} \to \sqrt{\alpha}\ S/\sqrt{B})$
- But a detailed analysis reveals some interesting features...
- Key observation:
  - Signal composed of both Charged Current (CC, with W boson echange) and Neutral Current (NC, with Z boson exchange)
  - Backgrounds (after VBF-like event selection) composed essentially of NC contributions (including also gluon exchange)
- Moreover
  - Reduced rates could be of some help for trigger
  - The presence of an additional photon can give an additional handle for trigger
  - It seems worth to be explored in detail...

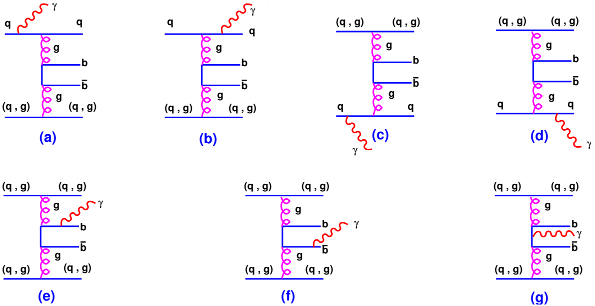
Signal

Both charged and neutral current contributions



Irreducible Background $b\bar{b}\gamma jj$

With typical VBF cuts (mainly a threshold on m_{jj} above M_Z, the main contributions come from only NC subprocesses)



- Gluons do not couple to photons
- γ radiation from separate fermionic current forms separate gauge invariant classes of diagrams

Large angle radiation suppression for NC

- The VBF cuts force the quarks to be in the fwd/bckwd region
- For NC the interference between radiation from in- and out-going legs is destructive for photon angles outside the cone given by the quark legs (angular ordering)
- $\Rightarrow$ the bulk of QED radiation is collinear to the in-/out-going quarks and is cut away if we require a central photon (see later)
- $\Rightarrow$ most of the contribution to the background is expected to come from final state b radiation, even if it is expected to be suppressed due to the $-1/3$ electric charge of b
- In the signal we expect the Z exchange contributions to be suppressed with respect to the W one. This would allow the separation of WWH and ZZH contributions
- the above semi-quantitative arguments have been tested with an explicit calculation (exact LO by means of ALPGEN and MADEVENT)

Event Selections

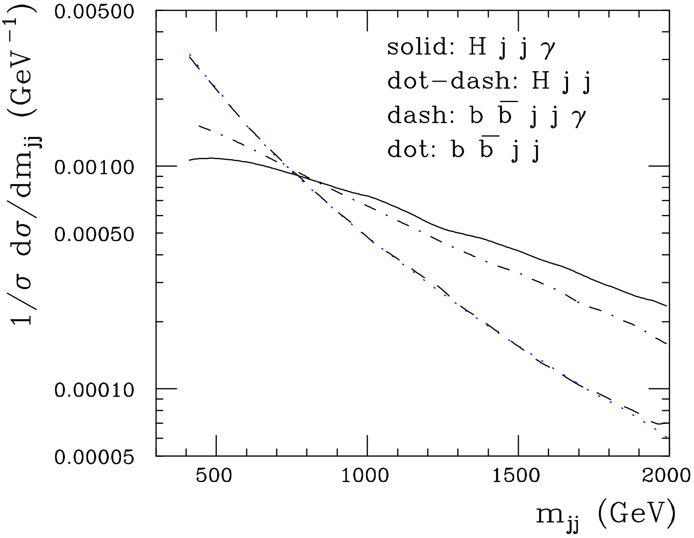
Basic cuts

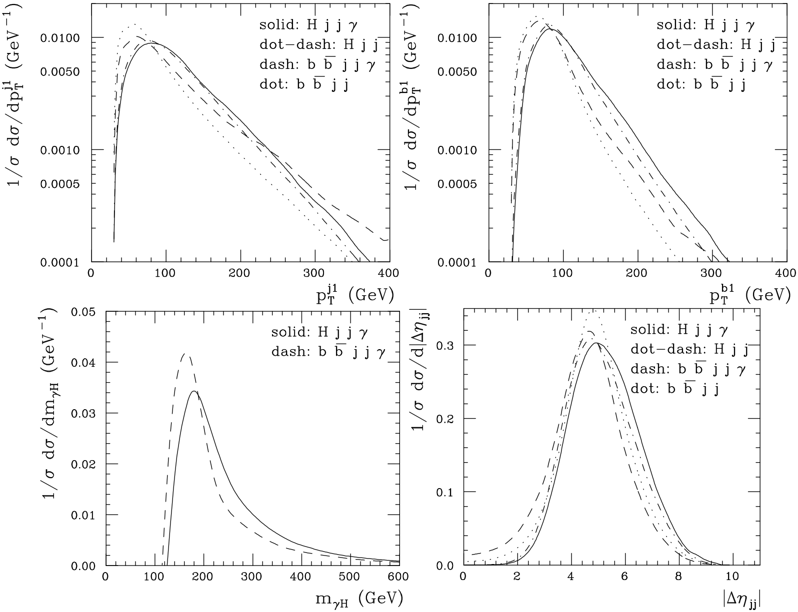
$$p_T^j \geq 30\,\mathrm{GeV}, \quad p_T^b \geq 30\,\mathrm{GeV}, \quad \Delta R_{ik} \geq 0.7,$$
$$|\eta_\gamma| \leq 2.5, \quad |\eta_b| \leq 2.5, \quad |\eta_j| \leq 5,$$
$$m_{jj} > 400\,\mathrm{GeV},$$
$$m_H(1-10\%) \leq m_{b\bar{b}} \leq m_H(1+10\%),$$
$$1)\;\; p_T^\gamma \geq 20\,\mathrm{GeV},$$
$$2)\;\; p_T^\gamma \geq 30\,\mathrm{GeV}$$

Optimized Cuts by looking at distributions ($m_H = 120$ GeV)

$$\frac{d\sigma}{dm_{jj}},\; \frac{d\sigma}{dp_T^{j1}},\; \frac{d\sigma}{dp_T^{b1}},\; \frac{d\sigma}{dm_{\gamma H}},\; \frac{d\sigma}{|\Delta\eta_{jj}|}$$

The most sensitive distribution




solid: H j j γ
dot−dash: H j j
dash: b $\bar{b}$ j j γ
dot: b $\bar{b}$ j j
$1/\sigma\ d\sigma/dp_T^{j1}$ (GeV^{-1})
p_T^{j1} (GeV)
$1/\sigma\ d\sigma/dp_T^{b1}$ (GeV^{-1})
p_T^{b1} (GeV)
solid: H j j γ
dash: b $\bar{b}$ j j γ
$1/\sigma\ d\sigma/dm_{\gamma H}$ (GeV^{-1})
$m_{\gamma H}$ (GeV)
$1/\sigma\ d\sigma/d|\Delta\eta_{jj}|$
$|\Delta\eta_{jj}|$

Optimized Cuts

$$m_{jj} \geq 800\,\mathrm{GeV}, \quad p_{\mathrm{T}}^{j1} \geq 60\,\mathrm{GeV}, \quad p_{\mathrm{T}}^{b1} \geq 60\,\mathrm{GeV},$$
$$|\Delta\eta_{jj}| > 4, \quad m_{\gamma H} \geq 160\,\mathrm{GeV}, \quad \Delta R_{\gamma b/\gamma j} \geq 1.2$$

Radiation suppressions for S and B

$$\frac{\sigma^{(N)}(H\gamma\, jj)}{\sigma^{(N)}(H\, jj)} = 0.0016$$

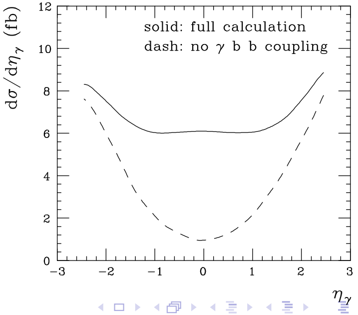
$$\frac{\sigma^{(C)}(H\gamma\, jj)}{\sigma^{(C)}(H\, jj)} = 0.013$$

$$N : qq \to H(\gamma)qq$$

$$q = (u, d, s, c, \bar{u}, \bar{d}, \bar{s}, \bar{c})$$

$$C : u\bar{c} \to H(\gamma)\, d\bar{s}$$

$$(8\ \text{processes})$$



Results for S and irreducible B

	$p_T^{\gamma,cut}$	$m_H = 120$	$m_H = 130$	$m_H = 140$
$\sigma[H(\to b\bar{b})\gamma jj]$	20 GeV	3.59(7) fb	2.92(4) fb	1.98(3) fb
	30 GeV	2.62(3) fb	2.10(2) fb	1.50(3) fb
$\sigma[b\bar{b}\gamma jj]$	20 GeV	33.5(1) fb	37.8(2) fb	40.2(1) fb
	30 GeV	25.7(1) fb	27.7(1) fb	28.9(2) fb
$\sigma[H(\to b\bar{b})jj]$		320(1) fb	254.8(6) fb	167.7(3) fb
$\sigma[b\bar{b}jj]$		103.4(2) pb	102.0(2) pb	98.4(2) pb

Backgrounds decrease by factors of about 3000!

	$p_T^{\gamma,cut}$	$m_H = 120$	$m_H = 130$	$m_H = 140$
$S/\sqrt{B}\|_{H\gamma jj}$	20 GeV	2.6	2.0	1.3
$S/\sqrt{B}\|_{H\gamma jj}$	30 GeV	2.2	1.7	1.2
$S/\sqrt{B}\|_{H jj}$		3.5	2.8	1.9

$L = 100$ fb^{-1}, $\epsilon_b = 0.6$

Considering also reducible backgrounds

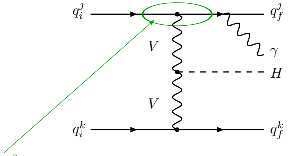
- $pp \to \gamma + 4$ jets
- $pp \to b\bar{b} + 3$ jets
- $pp \to 5$ jets

$$m_H = 120 \text{ GeV}$$

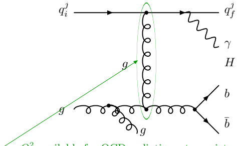
	$p_T^\gamma \geq 20$ GeV	$p_T^\gamma \geq 30$ GeV
$\sigma(pp \to \gamma + 4j)$	2.27(2) pb	1.72(4) pb
$\sigma(pp \to b\bar{b} + 3j)$	61.1(3) pb	45.1(2) pb
$\sigma(pp \to 5j)$	2.40(1) nb	1.83(1) nb
$S/\sqrt{B}$	2.2	1.8

$$\epsilon_{\text{fake}} = 0.01,\ \epsilon_{\gamma j} = 1/5000$$

Shower effect and jet veto

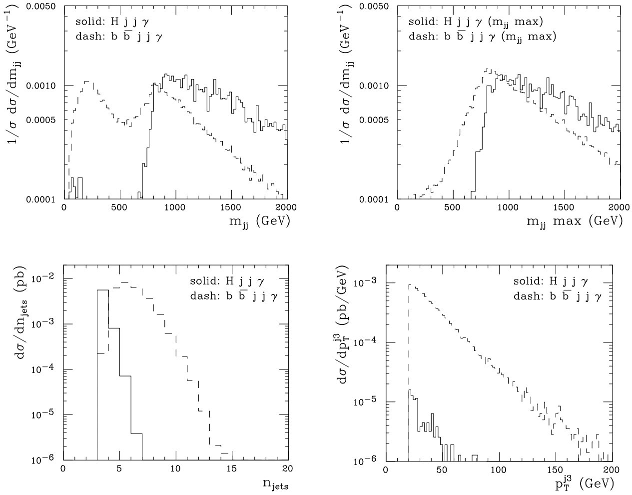


Q^2 available for QCD radiation, small rate for central jets



Large Q^2 available for QCD radiation, strong jet activity in central region

We tried to analyze these features by showering with Herwig two samples of unweighted events. A more solid approach would require a matching procedure to reduce the dependence on partonic cuts. To reduce edge effects we shifted the m_{jj} partonic invariant mass cut to 1 TeV with events generated with $m_{jj} > 800$ GeV


solid: H j j γ
dash: b b̄ j j γ
1/σ dσ/dm_jj (GeV^-1)
m_jj (GeV)
solid: H j j γ (m_jj max)
dash: b b̄ j j γ (m_jj max)
m_jj max (GeV)
dσ/dn_jets (pb)
n_jets
dσ/dp_T^j3 (pb/GeV)
p_T^j3 (GeV)

- After showering, only about 50% of the background events satisfy both the requirements for the tagging jets as leading p_{T} jets and the $m_{jj} > 1$ TeV requirement, while the effect is confined at the 7% level for the signal
- In addition to the above, a substantial fraction of the background events (about 50%) contain at least a third jets with η between the tagging jets and $p_{\mathrm{T}} \geq 20 - 30$ GeV, while only 2% of the signal events contain this additional radiation
- Showering and jet veto seem to allow for a substantial gain in statistical significance

Summary

- preliminary parton level studies show that $\gamma H(\to b\bar{b})$ VBF production could be promising, despite the drop in signal cross section (bckg cross sections decrease by about a factor of 3000!). It would allow also to separate HWW and HZZ contributions
- With optimized cuts statistical significances of more than 2σ at parton level for $m_H = 120$ GeV and 100 fb^{-1}
- Shower effects and jet veto strategies should improve substantially the above significance
- The correctness of the above picture should be tested with a complete experimental simulation
- The mechanism of bckg suppression is completely general (requirement: signal dominated by charged currents and background by neutral currents), it could also be at work for other channels